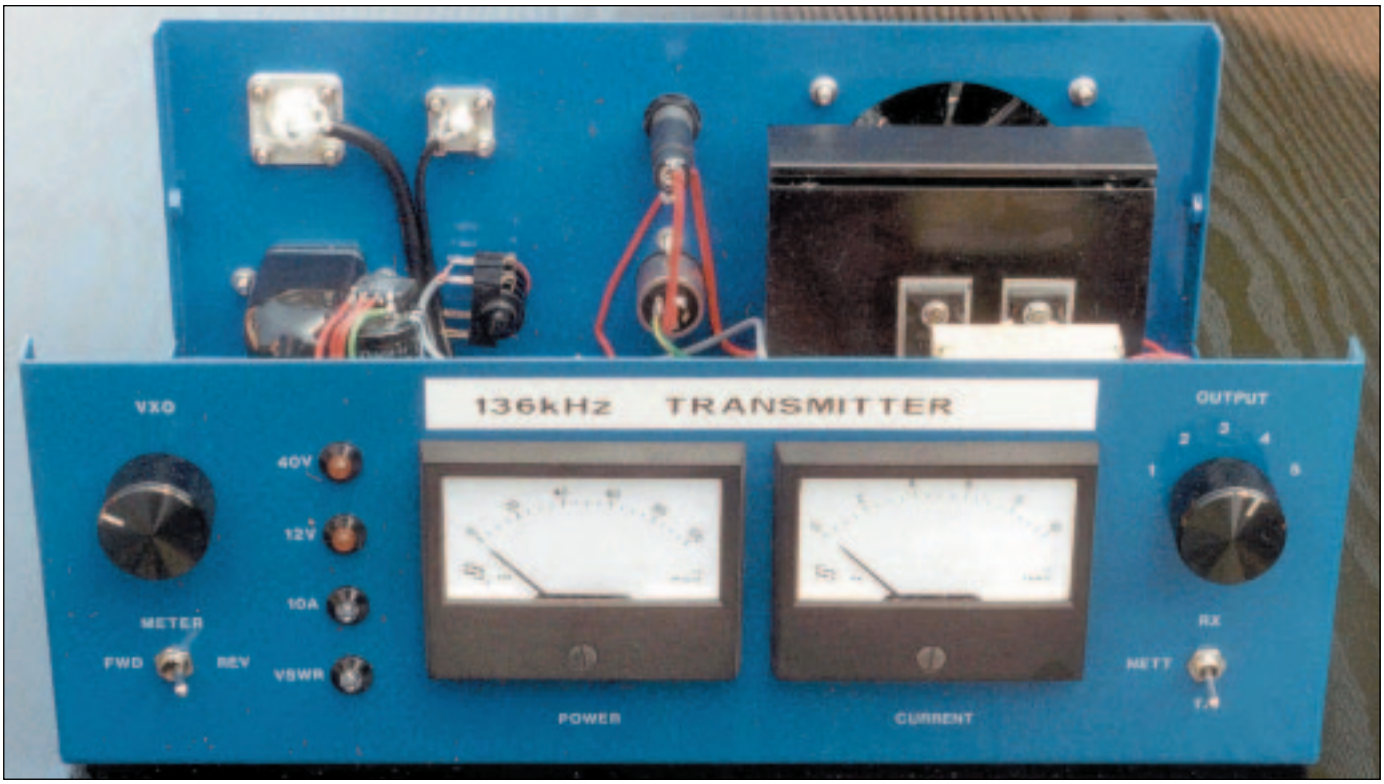
A Class-D Transmitter for 136kHz

Part one of a two-part 300W design by David Bowman, G0MRF *



The completed 136kHz transmitter, with its cover removed.

THE 136kHz low-frequency allocation was announced in the UK in February 1998. In the intervening five years, LF has been introduced in many countries, and there are now over 30 DXCC entities licensed for 135.7 to 137.8kHz. Several other administrations, including the United States and Canada, are considering similar allocations in the LF region and some have already issued experimental permits.

Initially, there was a degree of scepticism about the distances that could be worked with just 1W of effective radiated power. To put the DX potential into perspective, the Atlantic was first spanned with a cross-band QSO in September 2000 and currently, the two-way record is 5418km between Laurie, G3AQC, and VA3LK.

With no commercial equipment available from the established 'big four' manufacturers, LF designs have relied on individuals bringing a variety of ingenious ideas to the band. This transmitter combines a number of proven techniques and, with over 300W output, allows you to get on to this exciting amateur allocation with a good signal. The transmitter is based around an amplifier using two low-cost power FETs in a high-efficiency class-D configuration. The transmitter is protected against over-current and high-VSWR conditions. The single PCB also includes forward- and reflected-power metering, output filtering and transmit / receive switching.

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CIRCUIT DESCRIPTION

THE TRANSMIT DRIVE is generated by a pair of crystals operating as variable crystal oscillators. Crystal X1 is 8000kHz while Crystal X2 is 8274kHz (see **Fig 1** opposite). Each crystal is connected across a CMOS NAND gate, which functions as an oscillator. Varicap diodes are used for differential-tuning of the crystals. The two outputs are applied to a third NAND gate which, because logic gates are non-linear, functions as a mixer. The output of IC1(c) contains several products including the difference frequency at 274kHz. A low pass filter, comprising L1, C10 and C11, removes the high-order products, leaving a sine wave at twice the required output frequency. The filter is terminated by R7, which is part of the inverting amplifier IC2. C13 in the feedback loop adds some additional low-pass filtering before the signal is applied to the clock input of a 4013 D-type flip-flop. A small PCB jumper provides the option of driving the transmitter from an external source [1].

IC3 has two functions. Firstly, it divides the input frequency by two, producing 136kHz at the (Q) and (not Q) outputs. The second function of IC3 is to act as a switch in the event of a fault condition. In normal operation the Set Direct input, pin 8, is held at 0V by R16. The circuit uses D1 - D3 as a simple discrete OR gate to provide control and protection functions. Diodes D1 and D2

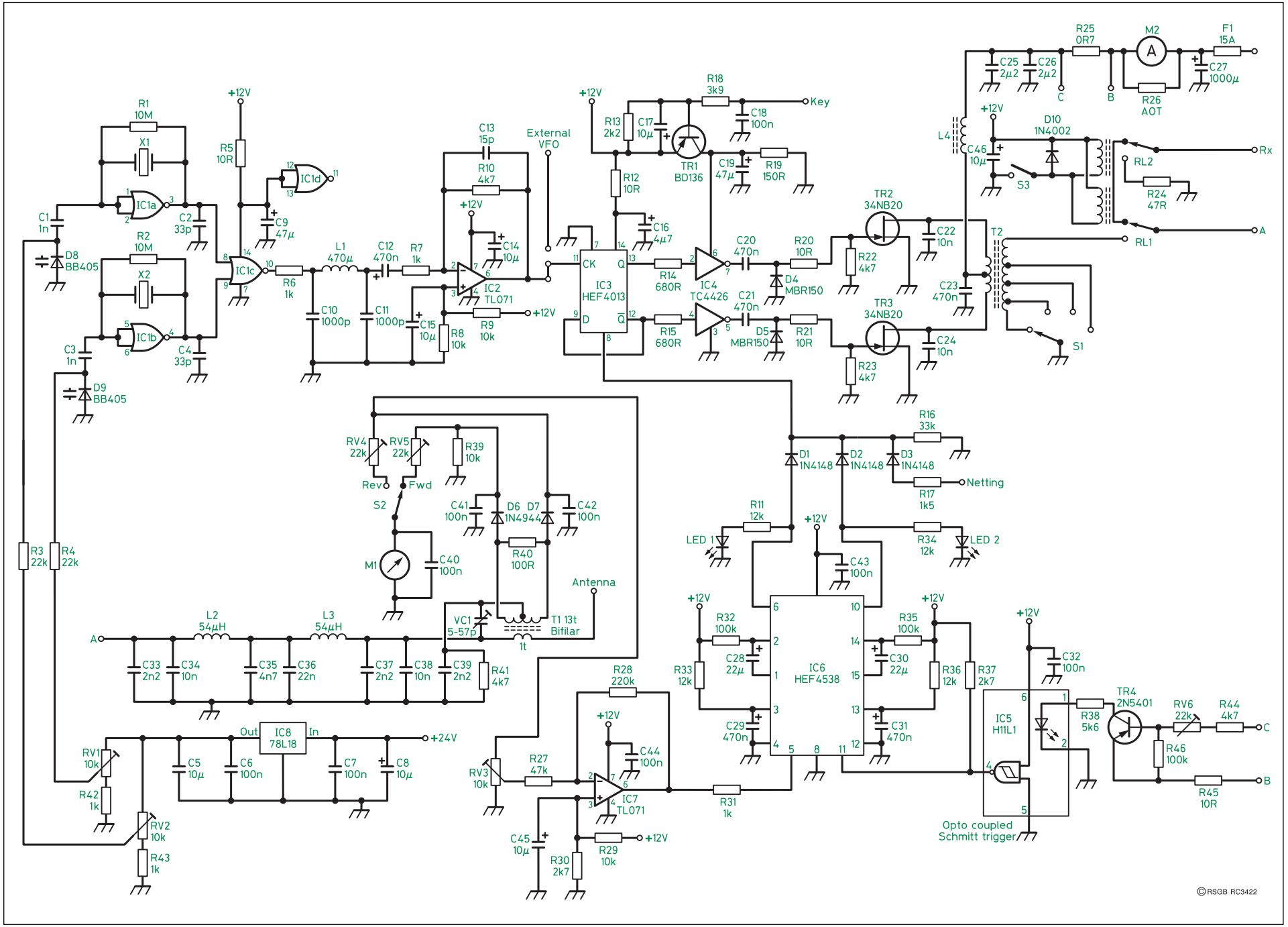


Fig 1: Complete circuit diagram of the 136kHz transmitter.

feed in signals from the reflected power and over-current protection circuits, while D3 is used to provide a netting facility on receive.

If D1 *or* D2 *or* D3 conduct, the Set Direct input will go to 12V, causing IC3 to shut down, removing the drive from the power amplifier. **Fig 2** shows how these functions can be controlled with a double-pole centre-off switch. One pole is used to drive the transmit / receive relays, while the other switches on a cooling fan during transmit periods.

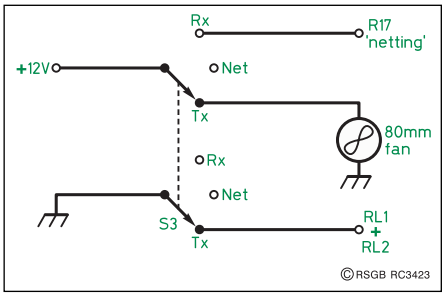


Fig 2: Transmit / receive switching, using a DPDT centre-off switch.

Netting is carried out with the switch in its centre-off position. This puts the relays in the receive position, but keeps the 4013 divider active.

IC4 is a dual-inverting FET driver. It amplifies the CMOS-level signal from IC3 and is capable of driving up to 1.5A into the gates of the power FETs. A fast charge / discharge time is essential for highly efficient, and disaster-free operation of a class-D amplifier. C20 and C21 AC-couple the drive to the FETs. Schottky diodes, D4 and D5, restore the correct DC level at the gates while R20 - R23 ensure stability.

The Class-D push-pull output stage comprises FETs TR2 and TR3 and output-matching transformer, T2. Initially, I selected a large E-core transformer for T2. This ETD44 core worked well, and was used in the prototype. Unfortunately, it proved both expensive and difficult to reproduce. Finally, it was replaced by a toroidal design, which was easier to construct. The drain-to-drain impedance of the FETs is matched to 50Ω by the turns ratio of T2. A series of taps on the secondary allows the turns ratio of T2 to be changed, allowing the power delivered to the antenna to be selected via a front panel ceramic switch. The highest number of secondary turns provides the highest output power.

The DC supply is passed through an ammeter and current-sense resistor and is decoupled by C26 and C27. DC is applied to the centre tap on the primary of T2. L4 and C23 provide additional filtering.

The RF output passes from the secondary of T2 through transmit / receive relay, RL1. A second relay, RL2, has been included to terminate the receiver input when in transmit mode. These relays are rated at 12A, and have been tested at 136kHz with power levels of 1000W. Diode D10 is included to protect any semiconductors included in the external switching arrangements.

From the relays, the RF passes through a multi-element low-pass filter to the output. The LPF is essential for removing the high levels of harmonics which are present in the square-wave output from the amplifier. The T157 core used for L3 is rated to about 400W, while the polypropylene capacitors are all specified at 1kV and are capable of handling much higher power levels. The cut-off frequency of the filter is 200kHz, ensuring a very low insertion loss at 136kHz.

REFLECTED POWER PROTECTION

FORWARD AND REFLECTED power are detected by directional coupler, T1. A single wire passing through the centre of the toroid acts as a single-turn primary, while the secondary is a bifilar winding of 13 turns. The secondary produces outputs proportional to forward and reflected power. These AC signals are rectified by diodes D6 and D7. Preset potentiometers, RV4 and RV5, set the sensitivity. Switch S2 selects whether forward or reflected power is displayed on the meter.

Resistors R29 and R30 define the reference voltage at the non-inverting input of IC7, and hence set the trip point of the protection circuit. Under normal operation, pin 6 of IC7 is at 12V. When the voltage at the wiper of RV3 exceeds the voltage at pin 3, the output at pin 6 rapidly falls from 12V to zero. This circuit was adapted from a Motorola application note [2] and is very fast-acting. It is claimed to be capable of switching off the drive in about 10µs. The op-amp output is connected to the input of IC6, a 4538 dual-monostable. Once triggered, the output of the monostable changes from 0V to 12V. This voltage forward-biases D1, which causes the Set Direct function of the 4013 to shut down the device. The output of the 4538 also illuminates a front panel LED giving a visual indication of the cause of the shutdown. Having cut off the drive, the monostable maintains this condition for a period determined by R32 and C28, about 2.2s. The circuit resets automatically.

OVER-CURRENT PROTECTION

OVER-CURRENT protection has been implemented by utilising current-sense resistor, R25, with TR4 and opto-coupler IC5. When the current flowing through R25 causes a potential difference of 0.7V to be developed across it, the pnp transistor, TR4, will switch on. Current then flows through R38 and the diode contained within the opto-coupler.

When the LED forward current reaches 600µA, an internal Schmitt trigger causes the output voltage to fall rapidly from 12V to zero. This triggers the other half of the dual-monostable, IC6. To preserve the speed of the over-current trip, there are no decoupling capacitors around TR4 or IC5. Once again, the response time of this circuit is very fast and it can reduce the output to zero in about 10-20µs. The exact value of the trip point can be adjusted over a small range by RV6.

CONSTRUCTION

THE PCB SHOULD be assembled and tested before being fitted into an enclosure. Start by constructing the VXO and logic circuits, leaving the low-pass filter coils, transformer T2, and directional coupler T1, until last. The power FETs can be temporarily fitted for testing and then mounted permanently after testing is complete. The coils L2 and L3 in the low-pass filter are quite large and can be held in place using a little epoxy glue for extra support. When fitting inductors, ensure that the enamelled wire does not come into direct contact with the earth plane. This avoids high voltages arcing through the thin insulation and other damage due to abrasion. The primary of T1 is a single wire passing through the centre of the toroid. I used a small length of the inner conductor from RG58 coaxial cable.

The powder-coated ready-punched enclosure used in the prototype is available from H J Morgan Smith [3].

NEXT MONTH

TESTING IS COVERED next month, together with some ideas on antennas for LF. Some consideration is also given to what you might expect to work on LF, and what computing equipment you would need for more sophisticated modes. There is also a list of components.

REFERENCES

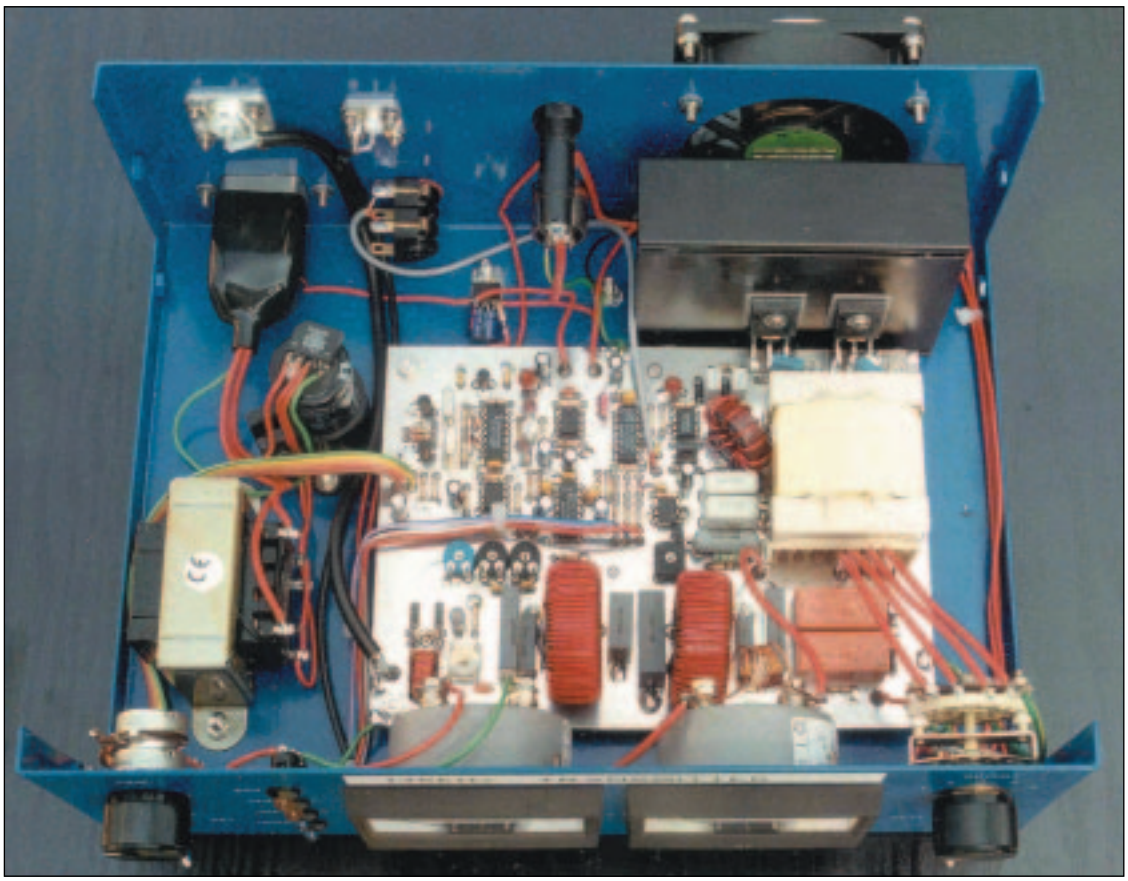
[1] PIC- or PC-controlled 0-6 MHz DDS VFO (AD9832). Johan Bodin, SM6LKM. **http://home4.swipnet.se/~w-41522/minidds/minidds.html**

[2] AR510: 'VSWR Protection of Solid State RF Power Amplifiers', by H O Granberg, *RF Design*, Feb 1991.

[3] H J Morgan Smith, sheet metal engineers. Tel: 01293 452 421. ♦

A Class-D Transmitter for 136kHz

The concluding part of the 300W design by David Bowman, G0MRF *



The inside of the transmitter, showing the disposition of the circuit board and the off-board components.

TESTING SHOULD FOLLOW a logical procedure. Apply DC to the 12V and tuning voltage inputs. Check that the two crystals in the VXO are oscillating by looking for the 8MHz signals at pin 8 and 9 of IC1. With the oscillators running and tuning correctly, you should be able to see 274kHz at pin 6 of IC2 and 136kHz at the (Q) and (not Q) outputs of the 4013.

The range of the VXO at 136kHz will be typically 1.5kHz. While this is not sufficient to cover the entire 2.1kHz allocation, it is possible to adjust the values of C2 and C4 and select which portion of the band you wish to cover. On my prototype, I decided to cover the slow CW (QRSS) portion at the top of the band, down through the CW section to 136.3kHz.

Start by setting all the presets to mid-position and VC1 to 80% mesh. Connect the output to a 50Ω dummy load. At LF, almost any load will suffice, even wire-wound resistors are a good match at 136kHz! Fit a 5A fuse temporarily to the main FET supply and switch on. Select the lowest power tap at six turns. Ground the transmit / receive pin and key the transmitter. If luck is on your side you should see between 50 and 100W output. Don't be tempted to switch to high power at this point. Instead, spend some time checking the other functions at this power level. Measure the efficiency of the amplifier and you should see a value above 70%. Values up to 86% are not uncommon. The power meter should read correctly but, if it reads backwards, this can be corrected by reversing the connections on the directional coupler. With a 50Ω load, the trimmer, VC1, can be adjusted to show zero reflected power. When you are satisfied that the transmitter is operating correctly, replace the fuse with a 15A component, and test at the higher power levels. The total number of turns on the secondary of T2 has been specified as 21. In practice, you may only need to use this number of turns if you are using a supply of around 36V. If you have a higher voltage (around 45V), you will be able to achieve maximum power output using the 18-turn tap.

The final part of the setting-up procedure is to adjust the reflected power and over-current trip points. I suggest that you turn up RV3 to maximum sensitivity and see how it responds. The current trip should be set for 10-11A with a supply of 36V, but if you're using a higher voltage supply, then the trip should be arranged to cut in at 400W DC input. At 45V supply, this equals 8.9A. Preset RV6 provides a fine adjustment of the over-

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current trip point. Coarse adjustments can be can be made by adding 1Ω 0.5W resistors in parallel with R25.

PRACTICAL ANTENNAS FOR LF

WITH A completed transmitter you're half way there. The only remaining problem is to choose an antenna and find some way of matching it to the transmitter. It's a popular misconception that you need huge antennas to be successful. However, you don't have to have access to a field and a 130ft tower to get good results. Practical antennas at 136kHz require a little ingenuity and care, but can be constructed with ease.

Three popular antennas are the Marconi T, an inverted-L or a simple vertical. As any choice will be electrically short ,you will need to arrange to resonate the antenna with a loading coil. **Fig 3** shows three possible arrangements: (a) is a loading coil in series with the antenna. Its function relies on the collective losses of the matching components and the earth system being approximately 50Ω; this arrangement has been found to work satisfactorily with simple earth systems and a wire antenna between 30 and 100m long; the arrangement has the advantage of having a high impedance when off resonance, offering extra protection to the transmitter; (b) and (c) show refined versions where a transformer or a tap on the loading coil can match a wide range of

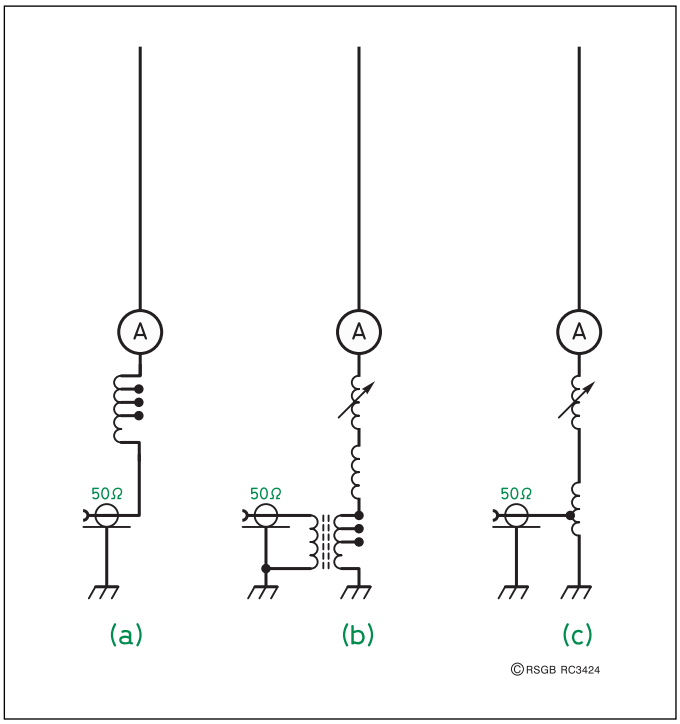


Fig 3: Antenna matching arrangements for LF.

COMPONENTS LIST

Resistors

R1, R2	10M	
R3, R4	22k	
R5, R12, R20, R21, R45	10R	
R6, R7, R31, R42, R43	1k	
R8, R9, R29, R39	10k	
R10, R41, R44	4k7	
R11, R33, R34, R36	12k	
R13	2k2	
R14, R15	680R	
R16	33k	
R17	1k5	
R18	3k9	
R19	150R	
R22	4k7	mounted off board
R23	4k7	mounted off board
R24	47R	
R25	R07	6W, RS Components. Shunt for 15A FSD
R26		
R27	47k	
R28	220k	
R30, R37	2k7	
R32, R35, R46	100k	
R38	5k6	
R40	100R	
RV1, RV2	10k	dual-gang potentiometer
RV3	10k	preset
RV4, RV5, RV6	22k	preset

Capacitors

C1, C3	1n	
C2, C4	33p	
C5, C8, C14, C15	10µ	
C17, C45, C46	10µ	
C6, C7	100n	
C9, C19	47µ	
C10, C11	1n	
C12, C29, C31	470n	electrolytic
C13	15p	
C16	4µ7	tantalum
C18, C32, C41, C42	100n	ceramic 50V
C20, C21	470n	polyester 63V
C22, C24	10n	50V pulse capacitors (polypropylene)
C23	470n	250V polyester
C25, C26	2µ2	100V polyester
C27	1000µ	63V - not on PCB
C28, C30	22µ	tantalum 16V
C33, C38	2n2	1kV polypropylene
C34, C37	10n	1kV polypropylene
C35	4n7	1kV polypropylene
C36	22n	1kV polypropylene
C39	2n2	polystyrene 160V
C40, C43, C44	100n	ceramic 50V

Semiconductors

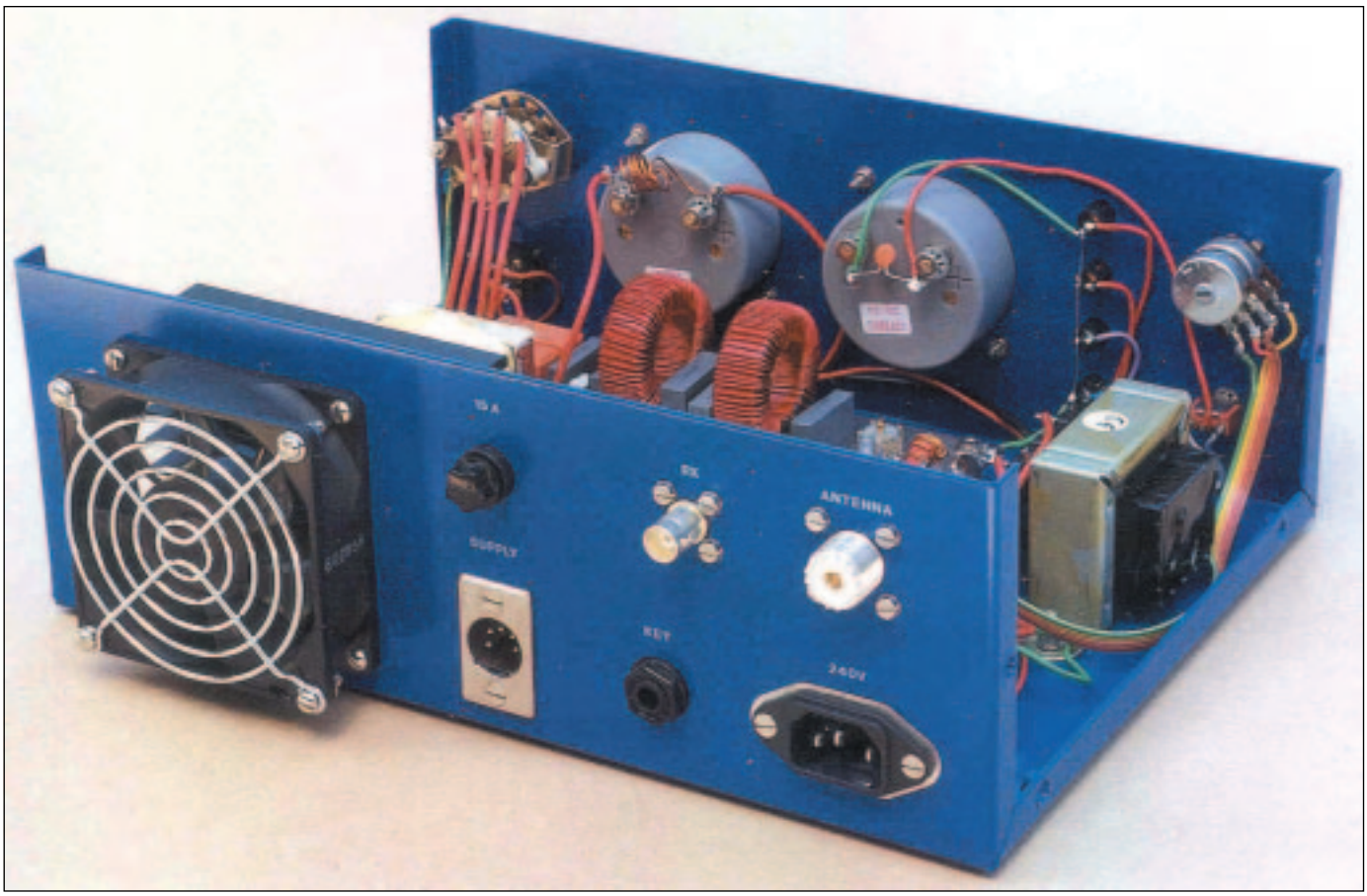
IC1	HEF4011B
IC2	TL071CN
IC3	HEF4013B
IC4	TC4426CPA
IC5	H11L1 Opto-isolator
IC6	HEF4538B
IC7	TL071CN
IC8	78L18AZ
D1, D2, D3	1N4148
D4, D5	MBR150
D6, D7	1N4944
D8, D9	BB405 varicaps
D10	1N4002
TR1	BD136
TR2, TR3	STW34NB20 MOSFET
TR4	2N5401
LED 1, LED 2, LED 3, LED 4	Two green for power: 12V and 40V. Two red ultrabright: VSWR and current trip.

Inductors

L1	470µH 7BA Toko
L2	54µH T157-2 powdered iron toroid. 59 turns of 0.8mm wire.
L3	54µH T157-2 powdered iron toroid. 59 turns of 0.8mm wire.
L4	11 turns 1.5mm on powdered iron toroid T94-2.
T1	Primary: 13 turns 0.4mm bifilar. Secondary: 1 turn (RG58 inner) on 15mm 3C85 ferrite.
T2	42mm 3C90 ferrite toroid Primary: 10 turns 1.5mm CT. Secondary: 21 turns 1mm with taps at 6, 10, 15, 18 turns.

Miscellaneous

X1	8.000 MHz crystal
X2	8.275 MHz crystal, QuartSlab. Fundamental mode, 20pF parallel load
RL1, RL2	12A relay. Single-pole change-over
VC1	5-57pF 809 series PTFE 300V trimmer, Farnell.
M1, M2	1mA FSD meter
S1	Rotary ceramic switch, single-pole 5-way, break-before-make.
S2	Forward / Reverse switch, single-pole 2-way switch.
S3	2-pole, centre-off toggle
Heat sink.	Single-sided 1.2°/W
Isolating washers	TO247
PCB	
Fan	80mm 12V, Farnell / Rapid / RS Components / Maplin, CPC, etc.



Rear view of the transmitter.

impedances. These latter two also have the important safety advantage of having a DC path to earth to discharge static. A thermocouple or RF ammeter can be used to monitor antenna current. Loading coils for LF are big, with a typical value between 1 and 10mH. They should be constructed from insulated wire because, at this power level, enamelled wire will fail as the insulation between turns is insufficient. Resonating the antenna system can be achieved by using a series of taps, or by making a small proportion of the inductance variable by including a variometer.

Finally, a word of caution: An electrically-short antenna will have very high voltages present - 20kV is not uncommon! Many antennas and kites have fallen from the sky at the instant the key is pressed. Use high quality materials, especially for the insulators and ensure that high-voltage sections are safely out of reach of family members and pets.

More information on LF antennas and operating techniques is available [4 - 6].

JOINING IN THE FUN

A GOOD GUIDE to LF reception in the UK is to listen for the German data transmitter, DCF39, on 138.83kHz. With a resonant antenna it should be S9+. The propagation characteristics of LF are broadly similar to topband. During daylight, the ground-wave predominates and, with a few hundred milliwatts ERP, it will be possible to work CW within the UK and into western Europe. At night, ground-wave and ionospheric propagation coexist. Alan Melia, G3NYK, has a website [7] which has a series of graphs showing the signal strength of the Canadian CFH transmitter on 137kHz, as received in the UK, and DCF39 as received in Portugal by CT1DRP. Most activity on the band is at the weekend, with normal CW operation taking place below 137.2kHz.

Finally, if you have a computer with a sound card, you can take part in some very weak-signal working. The upper and lower portions of the band are used for a technique known as QRSS or 'visual CW'. All the long-haul contacts have used this technique. By using either of two programs [8], you can use a computer to analyse the audio from your receiver. The computer uses a fast Fourier transform (FFT) to display very weak signals on the monitor. Speeds are very slow - a CW dot may take several seconds to send, but the technique is valuable, as the ability to turn your computer into a CW filter less than 1Hz wide allows you to see signals clearly that are many dB below the normal noise level.

A kit of parts for this project, or a PCB, is available from the author [5].

ACKNOWLEDGEMENTS

I WOULD LIKE to thank the following members of the LF community for their assistance: Dave Pick, G3YXM, and Peter Dodd, G3LDO, for circuit ideas; Bob, G8RW, André, N4ICK, and Mitch, VE3OT, for beta-testing prototypes; John, G4CNN (SK), for constructing a 400W version and producing the original circuit and component overlay drawings. Photographs by Maurice de Silva, G0WMD.

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www.wireless.org.uk

[5] G0MRF projects
www.g0mrf.freeserve.co.uk
Tel: 020 8572 8615.

[6] *Low Frequency Experimenter's Handbook*, edited by Peter Dodd, G3LDO (RSGB Shop).

[7] Alan Melia, G3NYK
www.alan.melia.btinternet.co.uk

[8] Two Windows-based programs can be used for weak signal reception. *Argo* or *Spectran* by I2PHD and IK2CZL, are available as freeware
www.weaksignals.com
QRS by ON7YD is used for transmitting slow CW.
All three programs from
www.wireless.org.uk/software.htm ♦